Cosmic ray rates on a surface Liquid Argon TPC

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Introduction

Some numbers re cosmic muons on a 50 kton LArTPC.

This note gives some calculations on the rates of cosmic muons and cosmic photons entering a Liquid Argon detector of mass 50 ktons situated on the surface of the earth at a height of 900 meters above sea level. The detector is based on a liquefied natural gas tank and is a cylinder with its axis vertical and with diameter the same as its height, $\approx$ 35.5m. Muons and photons are considered and the context is an accelerator-beam based experiment.
Cosmic rays could affect the experiment in (at least) four ways;

- they could generate so much data that the data-acquisition is overwhelmed and the experiment is not feasible.
- they might obscure such a large fraction of the volume of the detector that they overlap the events of interest to the point where the events cannot be reconstructed accurately.
- they might overwhelm the reconstruction and analysis such that the computing time required simply to remove the hits from cosmic rays and identify the neutrino interactions is prohibitive.
- they could generate interactions which mimic the neutrino events of interest.

Detector Parameters

The detector is characterized by the volume of argon, the anode to cathode distance (drift-distance) and the wire spacing. The present discussion is based on the following model. The drift-distance is 3 meters giving a maximum drift-time of 2 milliseconds at a drift field of 500 V/cm. The wire-spacing is set at 5 mm with 3 readout co-ordinates (vertical and $\pm 30^\circ$) resulting in $\approx 250,000$ wires. Each wire is equipped with a continuous wave-form digitizer running at 2 MHz and the detector therefore generates numbers at a rate of 5E11/second. A scheme of recording only differences between successive numbers [1] allows these numbers to be encoded into 3E11 bytes/second. The conceptual design of the readout system [2] allows for a total transfer rate of 5E9 bytes/second or about 16 milliseconds of the raw history of the entire detector per second.

Data Acquisition Challenge

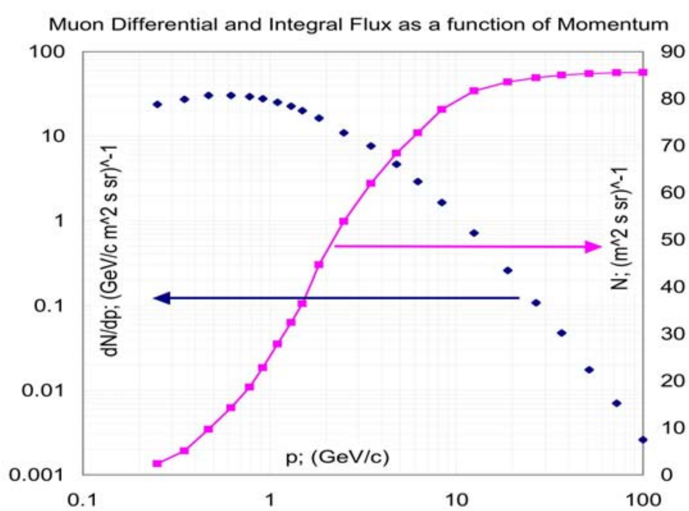
We assume there is no fast signal to define the time of a cosmic ray entering the detector. In this case if we wish to ensure that any cosmic ray entering the detector is *fully* reconstructed, the readout interval needs to cover from 2 milliseconds before the beam-spill to 4 milliseconds after the beam spill, for a total of 6 milliseconds. (The duration of the beam spill itself (10 microseconds if the source is the Fermilab Main Injector) is ignored)[3]. It is not essential, however, to record the full 2 milliseconds on either side of the valid drift-times to tag the track as coming from an out-of-time particle; any interval large compared to the few microsecond timing uncertainties (eg 1/5 of a millisecond) is sufficient. (If one imagines an algorithm where one uses signals from the outermost wires of each plane to identify cosmic rays, these wires, at least, need to be recorded for the full 6 milliseconds.)

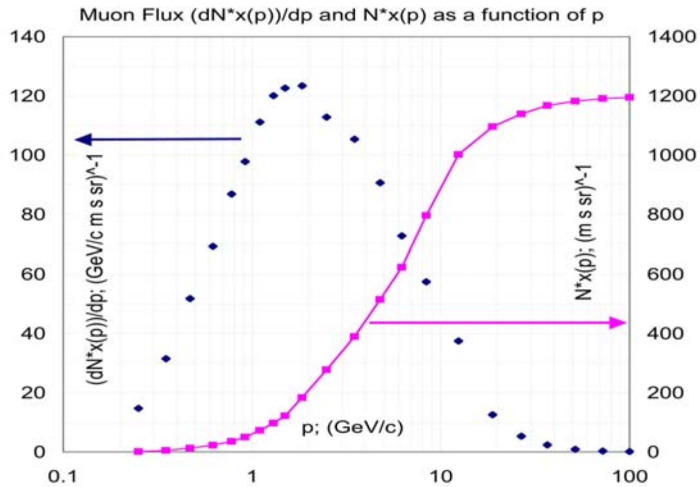
In any case, the data acquisition is capable of transferring 16 milliseconds of raw history allowing, as given above, for a beam-spill rate of 5 Hz. This is adequate for any machine cycle time proposed in the long baseline study [4].

Obscuring real events

The issue of background particles obscuring (confusing the reconstruction of) the events of interest *does* depends on the background rates. The rate of muon cosmic rays impinging on our 35.5 meter cylinder is 250 kHz. This number is calculated using a $cos^2(\theta)$ distribution independent of momentum and includes particles entering from the top and from the sides (1/2 of the total).

The muon spectra for the calculations are shown in the first two figures.





The first figure shows the momentum spectrum and the integral of the spectrum from a given momentum to 1 TeV (effectively infinite momentum). The spectrum of the total path length of muons (the product of the flux at a given momentum and the path length in liquid argon of a muon of that momentum) and the integral thereof is given in the second figure. (For a muon with sufficient energy to traverse the full detector, the path length contribution is set to 50 meters.) From the integral plot, it can be seen that about 1200 meters of muon path length cross a horizontal square meter per steradian per second.

In the two millisecond live time, about 500 cosmic muons enter the detector where each ray has a typical energy of 3 GeV and travels about 15 meters. If one considers that each ray obscures a square tube of side 1 cm along its path, and traverses the whole detector (a conservative assumption given the 15 meter average path) the fraction of the detector volume obscured is less than 1 part in 10^4. The number of cosmic photons entering is less than 1% of the muon rate and their impact on seeing the true events is negligible.

Burden on reconstruction

While the data acquisition can record the relevant data and the events are not obscured by the cosmic muons, identifying and removing the extraneous data from the muon tracks is a major challenge for successful operation of the detector. (We are distinguishing between the removal of extraneous signals from the cosmic rays so that one only looks at signals from neutrino interactions and the analysis to reject interactions of cosmic rays in the detector which contribute to the final event sample) At the least, one would prefer to avoid a situation where the mean time spent by a human being per spill is more than the time between spills. This means that the efficiency for rejecting cosmic rays in the analysis (while keeping the interactions of interest) must be very high.

The number of wires (in one co-ordinate) that a ray passes is ≈ 1000 and we may expect some 500,000 signals on the wires in one co-ordinate (7 tracks/wire) and about 1.5E6 signals total. The obvious scheme for identifying cosmic muons involves first finding lines in each co-ordinate separately. This is convenient logistically because it allows one to present the data to a set of of computers, each computer being assigned some number of wires and each working in parallel. We do not at this time have any numbers on how many computers are required nor on how efficient the process may be expected to be.

Cosmic Rays as a source of Background events

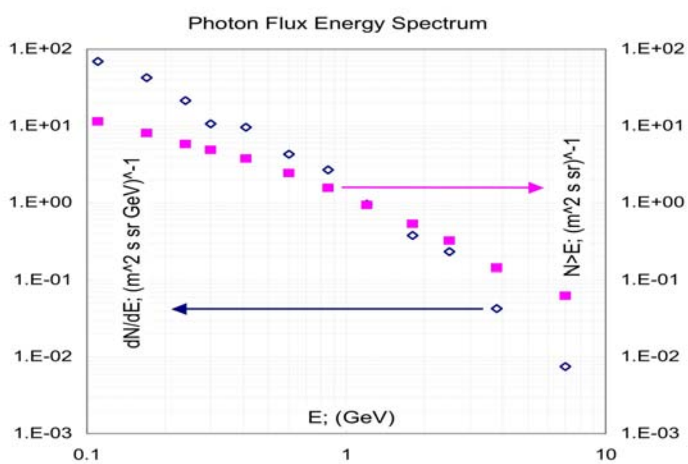
The last issue considered is background events from cosmic ray interactions in the detector. All that is done here is to establish the rejection rates required; the rejection we may expect still needs to be calculated.

Muons

The required rejection depends inversely on the number of protons-on-target (POT) per spill. A run of 15E20 POT at 3E13 POT per spill is 5E7 spills, and therefore about 2.5E10 cosmic muons will cross the detector. A rejection of better than 1E8 against these muons is probably required. Such a rejection requires understanding, for example, the rate of muon interactions which generate a neutron or photon which travels a distance of several centimeters before interacting.

Cosmic Photons

The cosmic photon flux impinging on the detector is about 1% of the muons; their spectrum is shown in the following figure.



The active volume is shielded by the iron shell of the tank and the meter or so of liquid argon. The total amount of material is about 6 photon interaction lengths thus reducing the flux into the active volume by a factor of 400. The rejection required is therefore about 5E3. Unlike the muon case where the muon tags its entry into the detector, photon conversions must be rejected directly. A number of parameters are available to do this including the absence of hadronic activity at the conversion point, the presence of a double minimum ionizing track at the conversion point, and the angle of the event with respect to the beam from Fermilab.

References

[1] S. Amerio et al., Considerations on the ICARUS Read-out and on Data Compression, ICARUS-TM/2002-05.

[2] High Capacity Data acquisition architecture - Bowden, Votava in http://lartpc-docdb.fnal.gov, document 81

[3] see http://lartpc-docdb.fnal.gov document 160

[4] For use in a DC beam (a muon factory or a beta-beam), the situation is more challenging. A surface detector would need a data-acquisition capable of transferring about 100 times as much raw data, or of rejecting data below threshold, fitting the wave-forms in real-time and passing reconstructed track positions. This would require a band-width of 250 kHZ (cosmic muon rate) $\times$ 3,000 (wires seen per muon) $\times$ 4 bytes (wire number, pulse height, position) = 3 Gb/s. This is within the capabilities of the proposed data acquisition system.

[5] Grieder, P.K.F. Cosmic Rays at Earth. Elsevier Science, 2001